MQXB17 Fabrication Report

TD-06-036

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1.0 Introduction

MQXB17 is the seventeenth of eighteen production cold masses to be built in the LHCIR Quadrupole series. Table 1.0.1 lists the previous cold masses in the MQXB series and the numbers assigned to the fabrication reports that describe them.

Cold Mass Number	Fabrication Report Number
MQXBP1 (prototype)	TD-02-009
MQXB01	TD-02-027
MQXB02	TD-02-038
MQXB03	TD-02-043
MQXB04	TD-03-004
MQXB05	TD-03-006
MQXB06	TD-03-022
MQXB07	TD-03-033
MQXB08	TD-03-036
MQXB09	TD-03-038
MQXB10	TD-04-038
MQXB11	TD-06-030
MQXB12	TD-06-031
MQXB13	TD-06-032
MQXB14	TD-06-033
MQXB15	TD-06-034
MQXB16	TD-06-035

Table 1.0.1 MQXB Cold Mass Fabrication Report Numbers

All the production cold masses (MQXB01-MQXB018) are essentially the same in design. They were preceded by one prototype, MQXBP1. Like all production cold masses, MQXB17 does not include R & D related instrumentation, such as quench detection voltage taps, spot heaters, strain gauges to measure coil azimuthal preload, or instrumentation on the longitudinal preload screws (bullets).

The primary features of MQXB17 are listed below in Table 1.0.2. Changes from the previous cold mass are highlighted in red and italicized.

Inner Cable Strand No.	37
Inner Strand Manufacturer	IGC
Inner Cable lay direction	Right Lay
Outer Cable Strand No.	46
Outer Strand Manufacturer	Outokumpu
Outer Cable lay direction	Left Lay
Cable Pre-baking	None
Strand Coating	None
Cable Cleaning Fluid	ABZOL VG
Inner Cable Insulation	25uM x 9.5mm w/ 58% overlap surrounded by 50uM x 9.5mm w/2mm gaps w/QIX
Outer Cable Insulation	25uM x 9.5mm w/ 50% overlap surrounded by 25uM x 9.5mm w/48% overlap w/QIX
Coil Curing temperature	190C/135C Two step cycle
Inner coil curing pressure	high at 135C/ low at 190C
Outer coil curing pressure	high at 135C/ low at 190C

Inner Coil target size	+300uM, (+.012 in)
Inner Coil target MOE	9GPa
Outer Coil target size	+250uM, (+.010 in)
Outer Coil target MOE	9GPa
Target Prestress	75-80 MPa
Coil end azimuthal Shim System	Shim ends to be same as body, tapering off toward end of saddle. See Figure 3.4.1.
End Part Material	G-11CR
End Part Configuration	Iteration #2, 5 block design.
Splice Configuration	Internal
Voltage Tap Plan	No Quench characterization voltage taps. Taps on leads at ends (between quadrants) only.
Inter layer strip heaters	None
Outer layer strip heaters	CERN version #2, double element, dwg. No. MD-369619.
Key extension	None
Inner coil Bearing Strips	None
Outer coil Bearing Strips	None
Collar configuration	38mm long solid welded packs, without bearing strips
Collar key configuration	152.4 mm long, phosphor bronze.
Strain Gauges	No beam or capacitor gauges.
Spot Heaters	None.
End Radial Support	Collet end clamps on both ends. Aluminum exterior cans with G-11CR quadrant pieces.
Collar/Yoke Interface	Radial clearance between collar and yoke.
Quadrant Lead Configuration	Double lead with superconducting cable for stabilizer
End longitudinal loading	Bullets apply load directly to coils, 8.9 kN (2000 lbs.) force per bullet. End cans are bolted to end plates, preventing coils from contracting longitudinally (see Figure 7.6.1).
Yoke Key Width	26.5mm
Strain Gauges on Skin	None.
End Plate Thickness	35mm
Tuning Shims	None
Other	Non-lead end keys mold released and replaced. Thermometers on end plates. Axial preload bolts not instrumented. Inner coils shimmed azimuthally 25 um toward midplane from original design. See section 4.3.

Coil Fabrication Start Date	08/20/2004
Cold Mass Completion Date	01/22/2005

Table 1.0.2 MQXB17 features.

2.0 Superconducting Cable

2.1 Cable Mechanical Parameters

Tables 2.1.1 and 2.1.2 summarize the cable dimensional parameters used in MQXB17. Inner cable came from reel LHC-3-I-N0008, and was made by New England Electric Wire Corp. using IGC strand. Outer cable came from reel LHC-4-K-B0815, and was made by LBL using Outokumpu strand. All cable was cleaned ultrasonically, at an elevated temperature (160C), with ABZOL VG, in a degreaser made by Branson Inc (the same machine used for the Tevatron). The degreaser is inserted into the cable insulating line, just before the cable is insulated.

PARAMETER	UNIT	INNER CABLE	OUTER CABLE
Radial width, bare	mm	15.4	15.4
Minor edge, bare	mm	1.320	1.051
Major edge, bare	mm	1.610	1.241
Midthickness, bare	mm	1.465	1.146
Keystone angle,	deg	1.079	0.707
Pitch Length	mm	114	102
Number of strands		37	46
Lay direction		Right	Left

Table 2.1.1: Cable design parameters for MQXB Magnets.

PARAMETER	UNIT	INNER CABLE (N0008)	OUTER CABLE (B0815)
Radial width, bare	mm	15.397	15.3960
Midthickness, bare	mm	1.4646	1.1460
Keystone angle,	deg	1.075	.682
Pitch Length	mm	109.2	101.6
Number of strands		37	46
Lay direction		Right	Left

Table 2.1.2: Cable actual parameters.

2.2 Cable Electrical Parameters

Electrical Data and cable test data in sections 2.2 and 2.3 were taken at BNL. Two tests of inner cable N0008 and two tests of outer cable B0815 were done. The ranges shown in the cable columns represent the range of values taken from the multiple tests.

PARAMETER	UNIT	INNER CABLE (N0008)	OUTER CABLE (B0815)
R(293 K)	μohms/cm	16.16	18.04-18.05
R(10 K)	μohms/cm	0.39	0.16-0.19
RRR		42	93-112
C/Sc		1.38	1.81-1.82

Table 2.2.1: Cable electrical parameters as provided by BNL

2.3 Cable Test Data

	INNER CABLE (N0008)		OUTER CABLE (B0815)	
B, T	I_c, KA	J_c, A/mm^2	I_c, KA	J_c, A/mm^2
6	19.811-19.422	2268-2332	12.573-13.633	2426-2455
7	14.357-14.400	1690-1695	9.364-10.018	1791-1811
8	8.988-9.293	1058-1094	6.155-6.402	1156-1167

Table 2.3.1: Cable test data at 4.2K as provided by BNL

3.0 Coil Fabrication

3.1 Cable and Wedge Insulation

Table 3.1.1 summarizes the cable insulation parameters used in MQXB17. Note that the adhesive on the outer wrap of both inner and outer cable is modified polyimide (QIX) instead of QI. QIX had been introduced late in the short magnet program. The wedges were insulated identically to their respective coils.

PARAMETER	INNER CABLE	OUTER CABLE
Number of wraps	2	2
Inner wrap:		
-material	Kapton tape 25 µm × 9.5 mm	Kapton tape 25 µm × 9.5 mm
-adhesive	None	None
-wrap structure	Spiral wrap with 58% overlap	Spiral wrap with 50 % overlap
Outer wrap:		
-material	Kapton tape 50 µm × 9.5 mm	Kapton tape 25 µm × 9.5 mm
-adhesive	Modified Polyimide (QIX)	Modified polyimide (QIX)
-wrap structure	Spiral wrap with 2 mm gaps	Spiral wrap with 48 % overlap

Table 3.1.1: Cable insulation parameters.

3.2 Winding and Curing

MQXB coils are cured using a two-step cycle (to control interstrand resistance) with low pressure/high temperature followed by a high pressure/low temperature step. All coils have wedge breaks staggered such that the breaks are not coincident at any longitudinal location in the same coil. Gaps between the wedges before curing are 2.2mm.

3.3 Coil Measurements

3.3.1 Coil Straight Section

Coil azimuthal size and modulus measurements were taken over a range of pressures, 55 to 100 MPa. The design pressure for both the inner and outer coils at room temperature is about 75-80 MPa. Coils are measured with a 3 inch (76mm) gauge length along the straight section of the magnet, from lead end to non-lead end. During this process, resistance measurements are taken to ensure that there are no turn-to-turn shorts.

The target sizes are +300 μm for inner coils and +250 μm for outer coils, at a pressure of 83 MPa. These values represent a size "with respect to the design size inside the cross section when the magnet is operating". The larger sizes are necessary at room temperature to achieve the correct sizes when the magnet is cold and powered. Table 3.3.1 lists the coils used and their corresponding average (unshimmed) size and modulus of elasticity.

Coil Numbers	SIDE A μm	E(A) GPa	SIDE B μm	E(B) GPa
MQXBi-098	210	9.6	217	9.7
MQXBi-099	228	8.4	239	8.4
MQXBi-100	215	9.2	222	8.9
MQXBi-101	221	8.8	238	8.6
MQXBo-086	196	10.1	197	10.0
MQXBo-087	195	11.1	194	11.1
MQXBo-088	225	10.2	223	10.9
MQXBo-089	217	10.7	224	10.9

Table 3.3.1: Coil body size and modulus.

Variation of the size along the length of the coils is shown in Figs 3.3.1 and 3.3.2. Side A is the "first wound" side of the coil and Side B is the side with the lead extending from the end of the saddle. The full length of each coil is measured, encompassing 67 positions, each 76mm long.

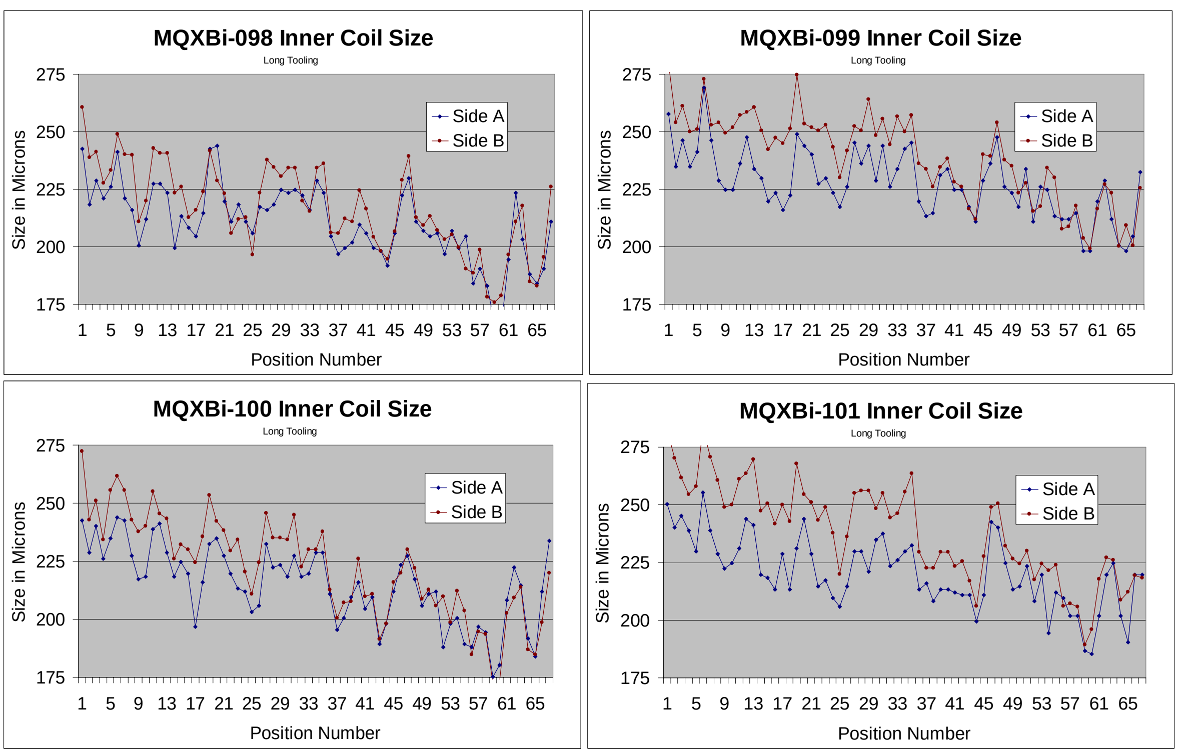

Figure 3.3.1: Variation of size along the length of inner coils.

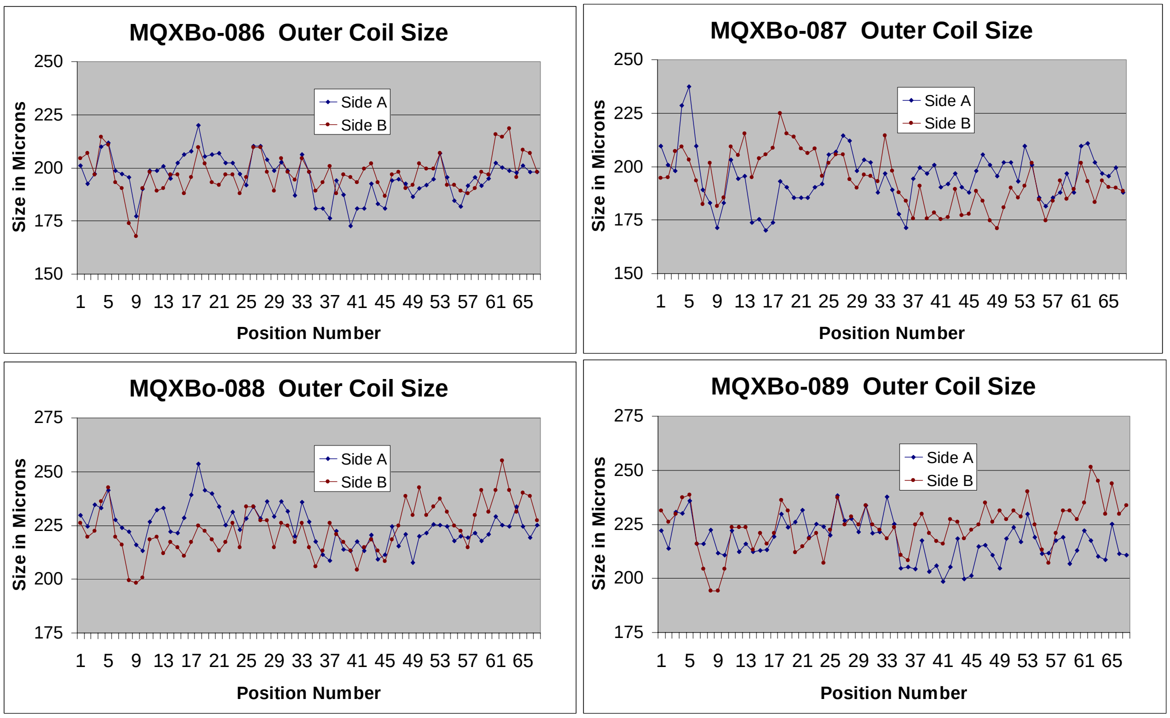

Figure 3.3.2: **Variation of size along the length of outer coils.**

3.3.2 Coil Length Measurements

MQXB coils are wound and cured using steel tooling which fixes the coil to a specific length. When a coil is removed from the tooling after curing, it shrinks longitudinally, relieving the stresses incurred during the coil and cable manufacturing processes. After curing, the straight section of each coil is measured longitudinally (back of key to back of key). "Springback" is defined as the difference between the coil length before curing and after being removed from the curing tooling. Measurements in mm are shown in Table 3.3.2.

Coil Number	Springback
MQXBi-098	6.4
MQXBi-099	6.4
MQXBi-100	6.4
MQXBi-101	6.4
MQXBo-086	Measurement error
MQXBo-087	Measurement error
MQXBo-088	Measurement error
MQXBo-089	Measurement error

Table 3.3.2: **"Springback", or Coil Longitudinal Shrinkage.**

3.4 Coil Shimming

3.4.1 Coil Straight Section

I/O	Quadrant	Coil #	Unshimmed Coil Size μm	Pole Shim μm	Midplane shim μm	Target μm	Shimmed Coil Size μm
Inner	1A	i-098	210	25	25	300	260
Inner	1B	i-098	217	25	25	300	267
Inner	2A	i-099	228	25	25	300	278
Inner	2B	i-099	239	25	25	300	289
Inner	3A	i-100	215	25	25	300	265
Inner	3B	i-100	222	25	25	300	272
Inner	4A	i-101	221	25	25	300	271
Inner	4B	i-101	238	25	25	300	288
Outer	1A	o-086	196	0	0	250	196
Outer	1B	o-086	197	0	0	250	197
Outer	2A	o-088	225	0	0	250	225
Outer	2B	o-088	223	0	0	250	223
Outer	3A	o-087	195	0	0	250	195
Outer	3B	o-087	194	0	0	250	194
Outer	4A	o-089	217	0	0	250	217
Outer	4B	o-089	224	0	0	250	224

Table 3.4.1: Kapton shimming used in the coil straight section.

If the magnet coil sizes do not meet the target, they may be azimuthally shimmed with Kapton to reach the target levels. The target pre-stress for MQXB17 is about 75-80 MPa. This corresponds to a nominal coil size of +300 μm for inner coils and +250 μm for outer coils. The inner coil sizes in MQXB17 varied from 210 to 239 μm with an average of 225 μm; whereas the outer coil size varied between 194 and 225 μm with an average of 210 μm. Inner coils were shimmed at the midplane by 50μm for preload adjustment.

Although not needed for preload adjustment, the inner coil pole and midplane were shimmed for harmonic purposes (see section 4.3 for a detailed explanation). Table 3.4.1 lists the coil and shim sizes used in MQXB17, and reflects the ground insulation changes shown in section 4.3.

3.4.2 Coil Ends

Resistance readings were taken while compressing the ends of the MQXB17 coils to 83 MPa, both lead and non-lead end of both inner and outer coils. Size measurements were not taken on the ends. The ends of the MQXB17 coils were shimmed azimuthally with sheets of 125 um thick Kapton, according to a formula that was established on the last short models (HGQ07-9), as are all long production coils. Shimming is shown in Figure 3.4.1 and is recorded in FNAL drawings 5520-MD-369695 and 5520-MD-369696. Dimensions in Figure 3.4.1 are in mm.

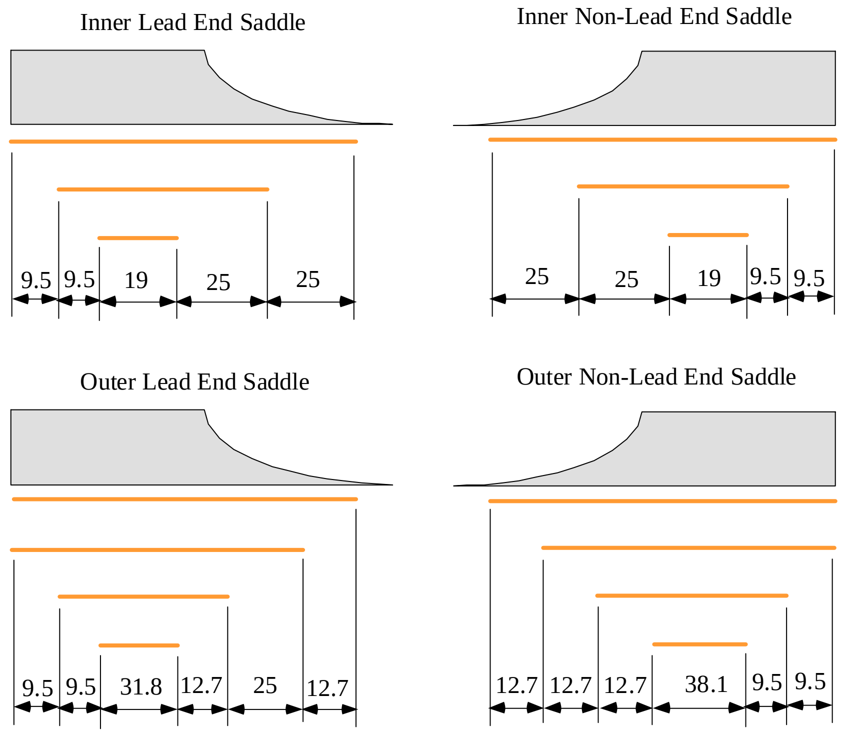

Figure 3.4.1: End Shimming.

3.5 Voltage Taps

Quench characterization voltage taps and spot heaters were not used on MQXB17, and are not used on any MQXB production magnets. As in all production magnets, MQXB17 includes ¼ coil taps, ½ coil taps, and taps on the leads as they exit the magnet.

4.0 Coil Assembly

4.1 Coil Arrangement

Coils in LHCIR Quadrupole magnets are arranged to obtain the most uniform possible preload distribution between quadrants, using the available coils. The coil arrangement is shown in Figure 4.1.1. The amount of shim placed at each pole and parting plane is shown in red (positive numbers indicate Kapton added, negative numbers indicate Kapton removed). Red numbers are in inches (.001 in. = 25 um). Shims may be added to (or removed from) the midplane and/or pole area to achieve the "target" azimuthal coil size and hence the desired preload. See also section 3.4 and 4.3 for discussions of coil shimming. The numbers in light blue in Figure 4.1.1 shown near each midplane (e.g., 222.5i, 209.5o, for Q1/2) show the "after arrangement and shimming" sizes of the inner and outer "octant pairs", respectively, in microns.

The shim sizes shown in Figure 4.1.1 are "with respect to the original design", that is, the positive and negative .001 inch (25um) shims shown at the inner coil pole and midplane respectively, represent the shim change for adjustment of harmonics described in section 4.3.

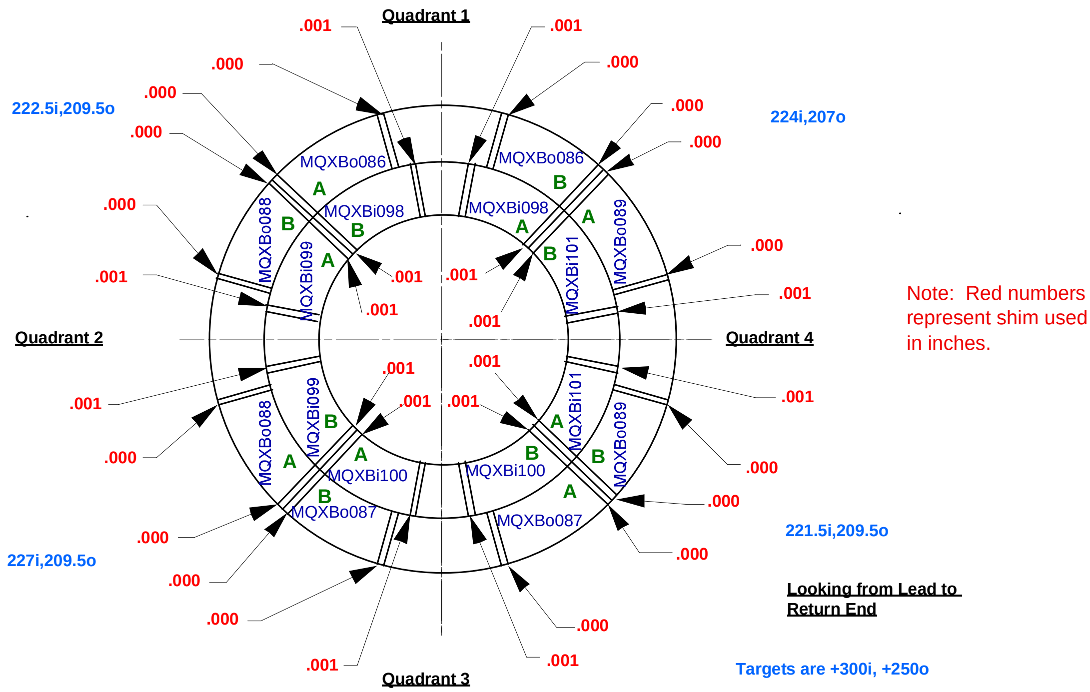

Figure 4.1.1 MQXB17 Coil Arrangement

4.2 Splices

The pole turns of each inner/outer coil pair need to be spliced together. Splices are 114 mm long, slightly greater than the cable transposition pitch. Areas to be spliced are preformed, and filled with solder before the coil is wound. The filled, or “tinned” sections are then spliced after the coils are assembled on the mandrel. The MQXB17 splices were made at 225 degrees C with 96% tin 4% silver solder using a Kester 135 flux.

All pole splices were insulated with two layers of Kapton tape, one layer of 25um thick × 9.5 mm wide surrounded by one layer of 50um thick × 9.5 mm wide. Both layers are spiral wrapped with 2 mm gaps. The second layer is wrapped directly on top of the first layer, leaving uncovered bare cable in the 2mm gaps. Axial and radial cooling channels were made in the G11CR spacers that surround the splice as well.

4.3 Ground Wrap System

The original design configuration for the coil ground wrap and insulation (used on MQXB01-3) is shown in Figure 4.3.1. All layers of Kapton are 125um (.005 inch) thick unless otherwise specified in the figure. A complete description of the original ground wrap system, including body and ends, is shown in assembly drawing #5520-MC-369659, Rev. B.

To improve harmonics, a series of minor changes were made to the system, beginning with MQXB04. The inner coils of magnet MQXB04 were shimmed toward the midplane by 38 um to reduce the normal dodecapole. Warm measurements of MQXB04 showed the 38um shift to be slightly more than necessary, so inner coils on later magnets, beginning with MQXB05, were shimmed only 25um toward the midplane with respect to the original design. Shim changes were done by modifying existing parts on MQXB04-MQXB06. Then, beginning with MQXB07, new parts were introduced which accomplish the change in coil position without modification at assembly. The ground wrap system used on MQXB07 and subsequent magnets (MQXB17 included) is shown in

Figure 4.3.2. This system, including ends, is shown in detail in assembly drawing #5520-MC-369659, Rev. C). A comprehensive description of the purpose of the changes, with detailed figures of the MQXB05 and MQXB06 systems, is shown in Section 4.3 of the MQXB04-6 Fabrication reports.

Quench protection heaters are placed radially between the outer coil and collar laminations. The heaters have stainless steel elements, .001 inch (25um) thick, .630 inches (16mm) wide, copper plated on one side. The copper is etched away intermittently over 4.00 inch (101.6mm) lengths, exposing the stainless, with 4.00 inch (101.6mm) lengths of copper plated areas between them. The stainless/copper element is sandwiched between (and bonded to) two pieces of .004 in. (100 micron) thick Kapton. They are described in detail in drawing #5520-MB-369369.

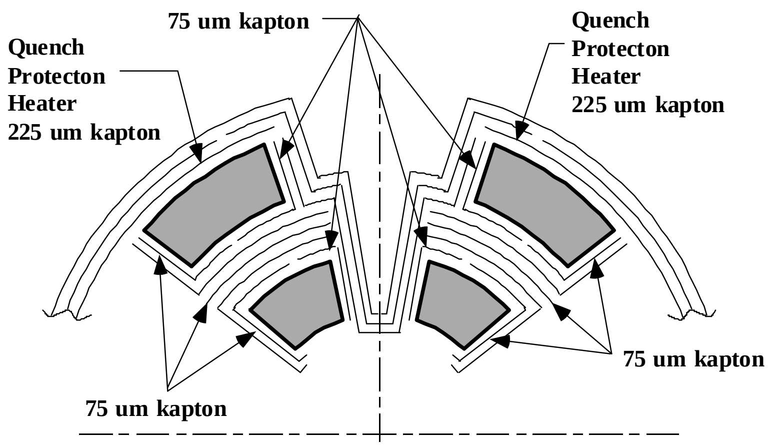

Figure 4.3.1 Original (MQXB01-3) Body Coil and Ground Insulation System

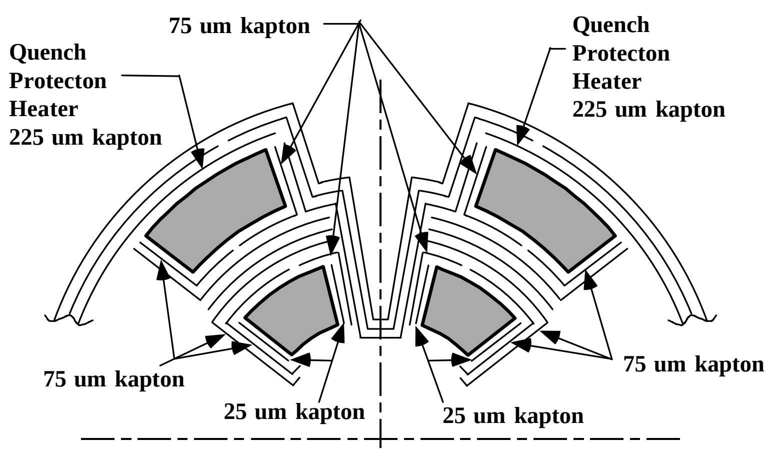

Figure 4.3.2 Modified (MQXB07 and subsequent magnets) Body Coil and Ground Insulation System

5.0 Collaring and Keying

5.1 Collaring

To ensure that the splices are aligned properly, the coils are assembled so that the back surfaces of the lead end keys of all four quadrants in both layers are coplanar. The back surfaces of the outer coil keys on the lead end are then "cut to fit" to allow the back of all four quadrant keys to be coplanar. On the non-lead end, the outer coil keys are cured into the coils. Their back surface defines the coil length after springback (springback is defined in section 3.3.2). The inner coil keys are cut to fit at assembly to make them coplanar (quadrant-to-quadrant variations in length created by differences in outer coil springback are small enough to ignore).

Collars are welded into packs, each 38mm long, with "large" and "small" alternating laminations, and shown in Figure 5.1.1. The collared coil assembly does not include bearing strips. Each collar pack is 25 laminations long, (~39 mm total length). Packs are made with a "large" lamination on each end, creating a gap between each collar pack in each quadrant, where a "small" lamination is missing. These gaps allow passage for heat flow.

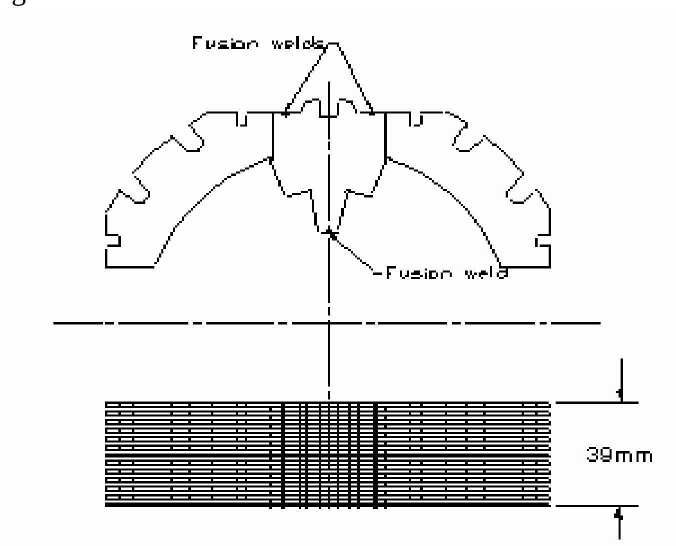

Figure 5.1.1: Collar pack.

5.2 Keying

MQXB17 was keyed according to procedure #TD-02-010. Collaring keys are 6 inches long. Steps (including press pressures used on MQXB17) are shown below. Passes are done in 6 inch increments, aligned with the keys, unless otherwise noted.

1)Massage at 900 pump psi main cylinder pressure
2)Massage at 1800 pump psi main cylinder pressure
3)Partial key insertion with main cylinder pressure 3000 pump psi/key cylinder pressure 700 pump psi
4)Full key insertion pass with main cylinder pressure increased to 4000 pump psi and key cylinder pressure increased to 2700 pump psi
5) 2nd full key insertion pass with main cylinder pressure increased to4400 pump psi and key cylinder pressure increased to 3300 pump psi
6) 3rd full key insertion pass with main cylinder pressure increased to 5000 pump psi and key cylinder pressure increased to 3600 pump psi, done in 3 inch increments.
7) 4th full key insertion pass with main cylinder pressure maintained at 5000 pump psi and key cylinder pressure increased to 4000 pump psi, done in 3 inch increments.
8) Final pass straddling keys at 5000 pump psi main cylinder pressure and 4000 pump psi key cylinder pressure.

5.3 Mechanical measurements

The outside collar diameter measurement data for the collared coil assembly is shown in Figures 5.3.2-5.3.3. The measurements are taken from the non-lead end to the lead end of the collared area (as shown in Figure 5.3.1), approximately every 8 cm (three inches). Diameters are displayed in the figures in mm.

Figure 5.3.1: Collared coil assembly without end clamps installed.

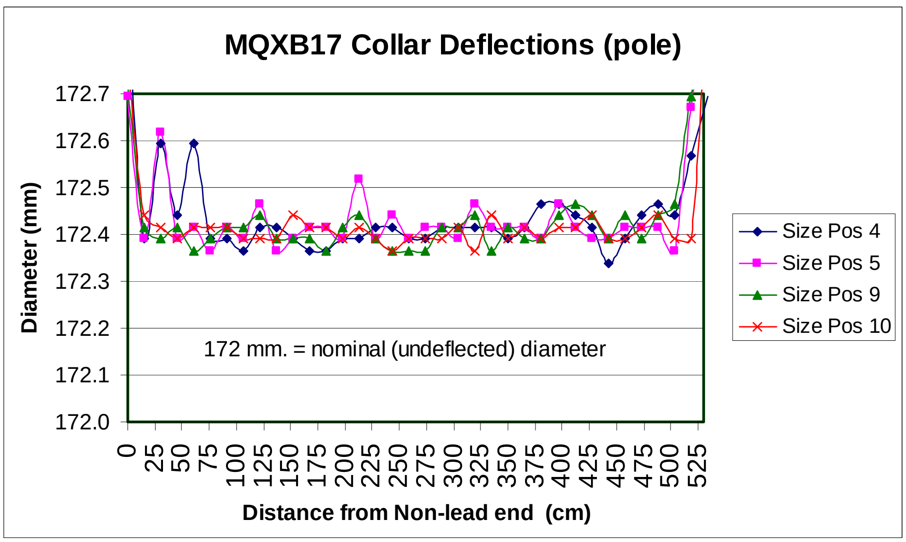

Figure 5.3.2: Collared coil deflections at pole region after keying.

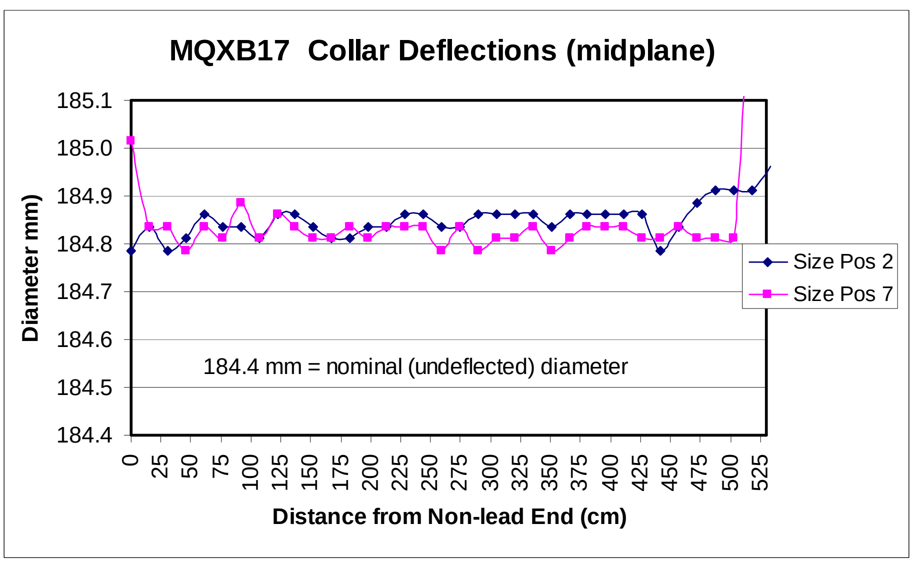

Figure 5.3.3: Collared coil deflections at midplane region after keying.

The measurements show a mean radial deflection of 220 um at the midplane and 204 um at the pole. When adjusted for actual collar lamination sizes (the plots in Figures 5.3.2 and 5.3.3, above, do not reflect these adjustments), these deflections are similar to that of the last two short models, HGQ08 and HGQ09 and previous long magnets, as shown in Table 5.3.1 and Figure 5.3.4, indicating a similar preload. (Measurements for MQXB04 are not available).

After keying is complete, the magnet body is measured longitudinally, and the center of the magnetic length is marked on the collar surface. This mark will be transferred to the skin surface during the yoking process.

Magnet No.	Adjusted Midplane	Pole	Unadjusted Midplane	Pole
HGQ07			117	108
HGQ08	222	237	165	180
HGQ09	154	159	115	120
P1	197	202	249	254
MQXB01	176	174	228	226
MQXB02	156	160	208	212
MQXB03	187	188	239	240
MQXB05	163	174	215	226
MQXB06	137	150	189	202
MQXB07	164	167	216	219
MQXB08	155	150	207	202
MQXB09	163	154	215	206
MQXB10	196	200	248	252
MQXB11	182	187	234	239
MQXB12	181	180	233	232
MQXB13	167	175	219	227
MQXB14	174	174	226	226
MQXB15	164	147	216	199
MQXB16	181	189	233	241
MQXB17	168	152	220	204

Table 5.3.1: Collared coil deflections of HGQ07-MQXB17.

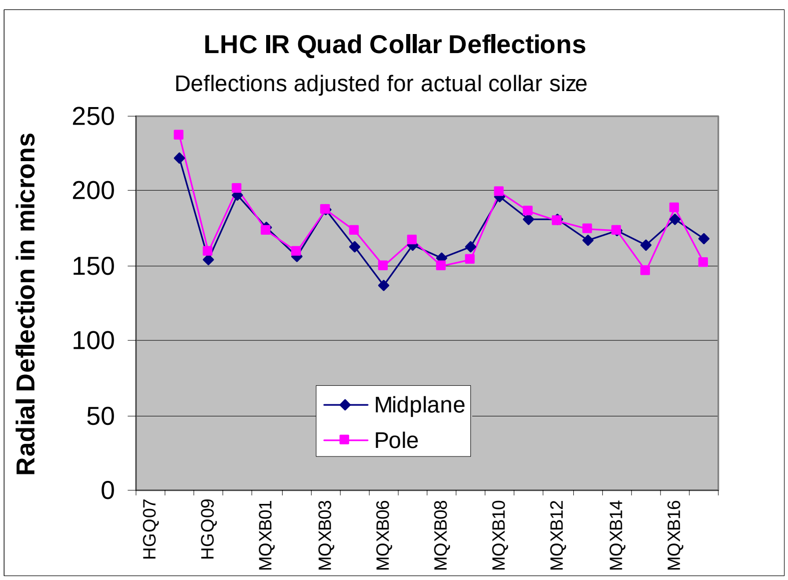

Figure 5.3.4: Collared coil deflections of HGQ07-MQXB17.

6.0 End Clamps

6.1 Installation Procedure:

The lead end clamp on MQXB17 is 249.8mm long and the non-lead end clamp is 131.9 mm long. G-11 filler cones were used. Longitudinal force required to close the "collet' end clamps was 448 kN (100,781 lbs.) on the lead end and 179 kN (40,312 lbs.) on the non-lead end.

6.2 Measurements and Shimming:

The production cold mass design allows for extra radial ground insulation to be added around the outer coil ends, if needed, to adjust the end preload. Based on measurements of short models and P1 (the full size prototype), the thickness of radial ground insulation surrounding the outer coil ends was increased by 75 microns (on the radius) at both ends from the original design, beginning with MQXB01 (see the P1 Fabrication report, TD-02-009, for more details), and continuing through MQXB04. Beginning with MQXB05, the shim was removed due to concerns about the shorts in the transition area between the body and ends, and because an acceptable deflection was achieved without it. No shim was used on MQXB17. The deflections of the diameter of the aluminum end cans according to micrometer measurements are shown below in Figure 6.2.1 (target diameter change from FEA, was 250 - 300 microns at the LE and 200-250 microns at the non-LE).

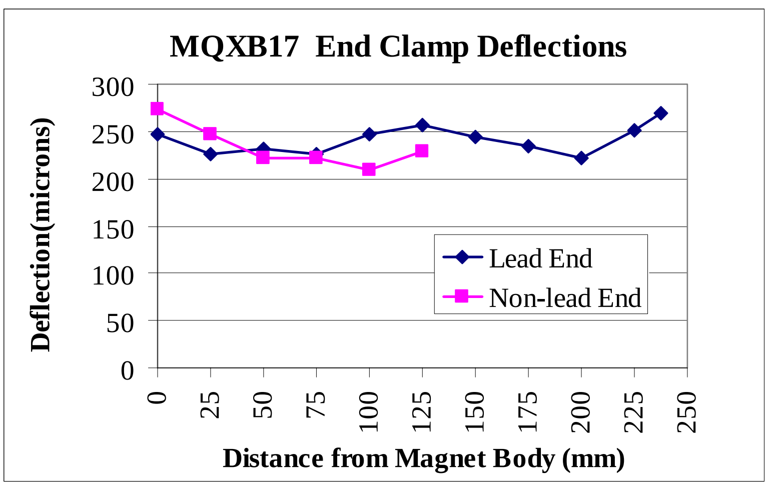

Figure 6.2.1: Aluminum End Can Radial Deflection (Diameter)

7.0 Yoke and Skinning

7.1 Assembly Configuration:

All yoke lamination packs were fusion welded longitudinally in 7 places (5 welds on outer surface and 2 welds on inner surface). 9 stainless steel laminations were welded to the lead end side of the straight section yoke, and 21 on the non-lead end. Stainless steel modified yoke laminations were used for both lead and non-lead ends to cover the end cans. Figure 7.1.1 shows the design length and the layout of the yoke laminations during assembly. Actual length between end cans was 5222.9 mm, 8.1 mm shorter than the design, primarily due to coil shrinkage after curing. The actual total coil length is therefore also shorter than the design by a similar amount.

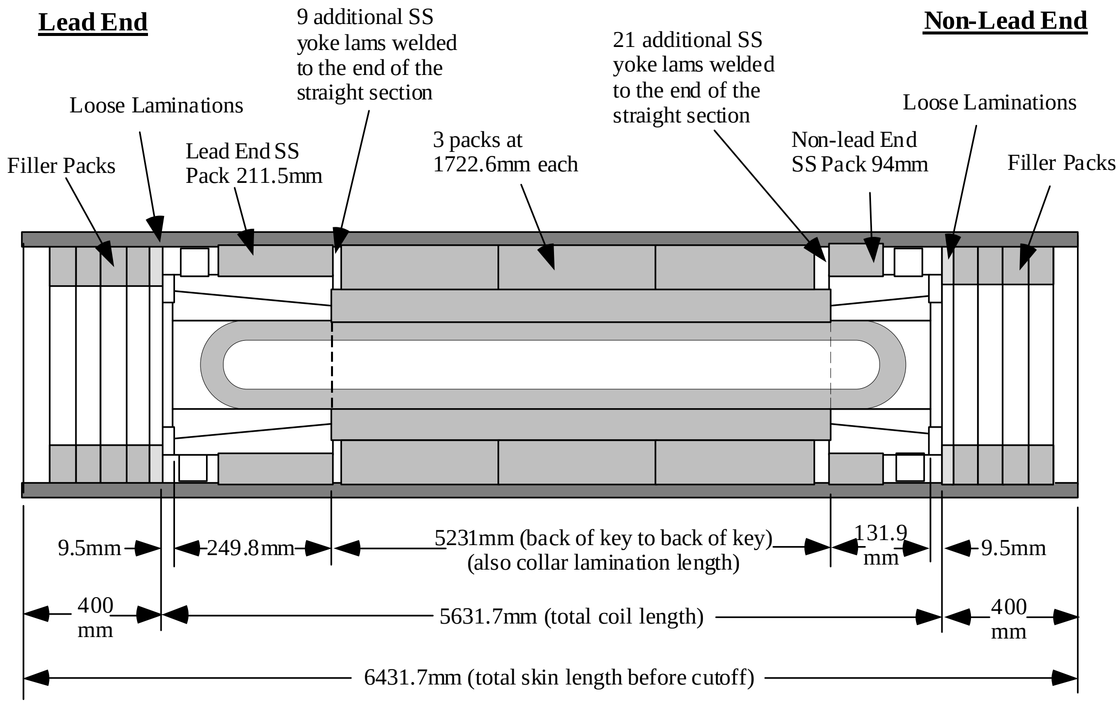

Figure 7.1.1: Yoke Assembly Configuration Before Welding

7.2 Welding:

The skin alignment key was 26.5 mm wide for MQXB17, as are all the long magnets. The 26.5-mm wide skin alignment key leaves a gap of 3mm (.12 in.) between the upper yoke and the upper skin; also a 3mm (.12 in.) gap between the lower yoke pack and skin alignment key. The total gap allowed for weld shrinkage is 6mm (.24 in.).

The magnet was compressed in the contact tooling with a hydraulic press pump pressure of 4MPa (600 PSI) during welding, corresponding to a force of about 23700 kg/meter (16000 lbs./ft) of magnet length. A pressure above 3.3MPa (500 PSI) must be applied to completely collapse the springs in the wheel units of the bottom tooling. First a fusion pass, then, consecutively, four filler passes were applied. After welding, the skin was cut to length, and the end plates were welded.

7.3 Outside Diameter Measurements:

Skin outside diameter measurements were taken at different angles after welding the end plates, at the angles shown in Figure 7.3.1. Data and plots are shown in Table 7.3.1 and Figure 7.3.2 (values in mm).

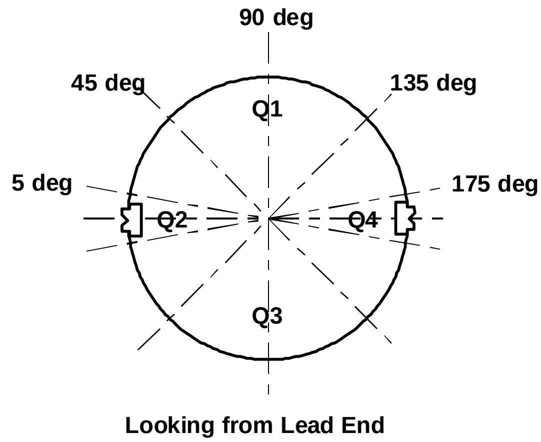

Figure 7.3.1: Yoke Outside Diameter Measurement Positions

Distance from LE (in.)	Distance from LE (meters)	5 deg.	45 deg	90 deg	135 deg	175 deg
0	0.0	418.9	415.5	414.4	415.4	417.8
50	1.3	416.0	416.0	415.9	416.3	416.4
100	2.5	416.9	416.3	416.0	416.0	416.4
150	3.8	416.9	416.3	416.5	416.1	416.5
200	5.1	416.4	415.9	415.9	416.2	417.0
240	6.1	417.0	415.2	415.3	415.2	417.5
	Mean (body)	416.5	416.1	416.1	416.1	416.6

Table 7.3.1: Yoke outer diameter according to micrometer measurements taken at different angular positions between skin alignment keys

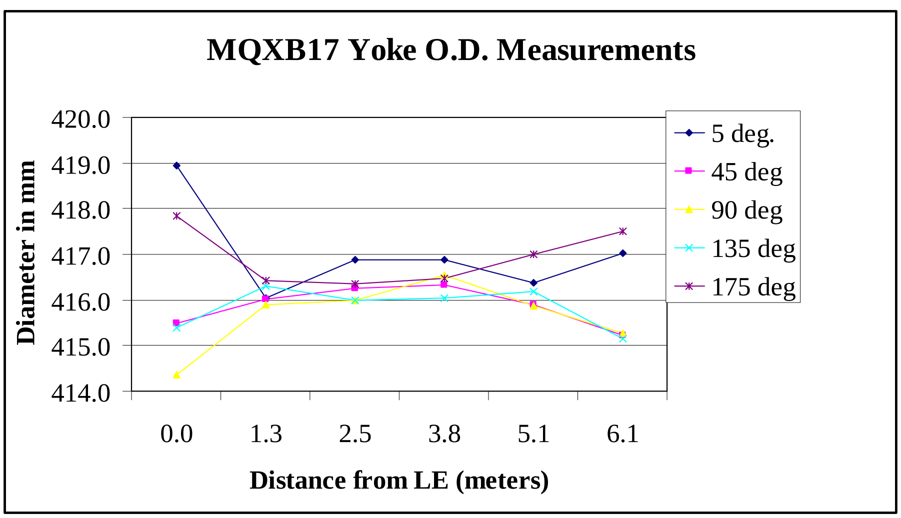

Figure 7.3.2: Yoke Outer Diameter Measurements Plotted

7.4 Twist Measurements:

The twist in the cold-mass assembly after welding the skin and the end plates was measured on a granite table with a level and is shown in Figure 7.4.1. The twist was measured to be -0.188 milli-radians per meter in the straight section of the magnet (rms). The allowed twist for the MQXB Cold Mass is less than 0.2 milli-radians per meter.

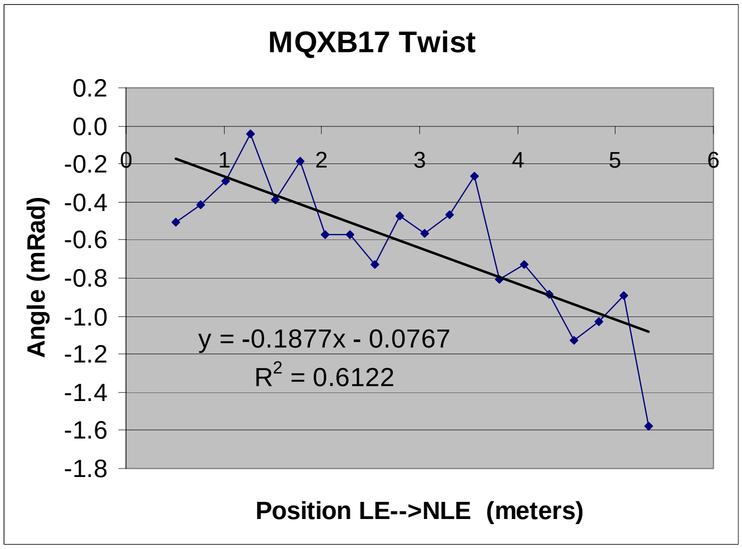

Fig 7.4.1: Cold Mass Assembly Twist Measurements

7.5 Straightness Measurements

Straightness of the yoke in both the vertical and horizontal axis is taken by measuring the distance between the skin surface and a stretched wire. Measurement positions are described in Figure 7.5.1 and shown for MQXB17 below in Table 7.5.1. The wire is stretched across the length of the skin, touching on each end. Measurements are taken from the wire to the skin. Positive numbers, therefore, in Table 7.5.1 represent concavity on the surface noted. A straight or convex condition will result in zero readings.

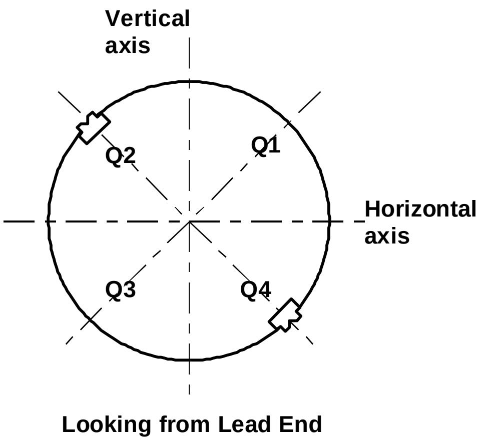

Figure 7.5.1: Straightness Measurement Positions

meters	microns	microns	microns	microns
Distance from Lead End Plate	Vertical Measurement top	Vertical Measurement bottom	Horizontal Measurement left	Horizontal Measurement right
LE Plate	0	0	0	0
0.3	0	0	0	0
0.6	0	0	0	25
0.9	0	0	25	25
1.2	0	0	50	25
1.5	0	25	50	25
1.8	0	25	75	0
2.1	0	0	75	0
2.4	25	0	75	0
2.7	25	0	75	25
3.1	25	25	50	0
3.4	25	25	75	0
3.7	25	25	50	0
4.0	25	25	75	0
4.3	0	0	25	25
4.6	0	0	75	25
4.9	0	0	25	0
5.2	0	0	25	25
5.5	0	0	25	0
NLE Plate	0	0	0	0

Table 7.5.1: Straightness Measurements

7.6 Axial Loading (Bullets & Bolts):

The axial support system of the magnet is shown below in Figure 7.6.1:

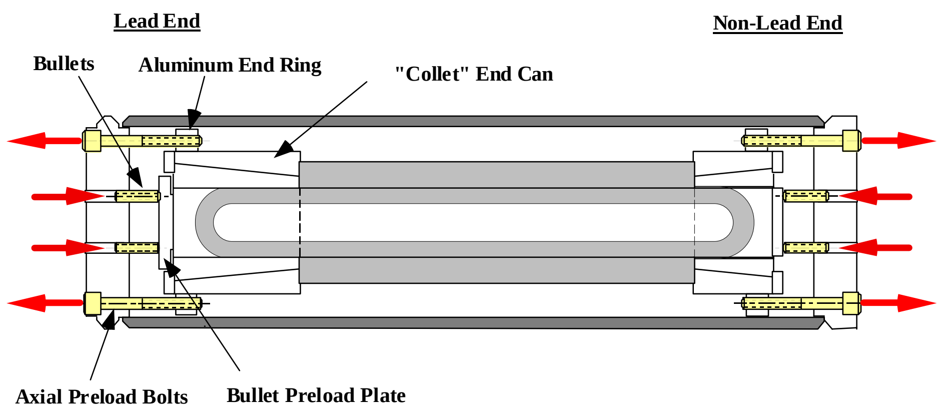

Figure 7.6.1: Axial Support of the Cold Mass Assembly

End load is applied by hand tightening the bullets to the bullet preload plate, then tightening the axial preload bolts to the specified amount. As on all production magnets, strain gauges to read longitudinal load were not used on MQXB11. Torque applied to bullets was established from strain gauge readings of short models and the prototype. The complete bullet tightening procedure is explained in FNAL document # 5520-ES-369708, Bullet Torque Specification for LHCIR Quad MQXB Magnets. Each of the four bolts are tightened with a torque wrench, to 1200 inch-lbs. With that torque, each bolt applies 35.6 kN (8,000-lbs.) tension load to the magnet. As a result of the loading of the magnet with bolts, the bullets are subjected to a compressive load of 8.9 kN (2,000 lbs.) each. The total force applied to the magnet is therefore 107 kN (24,000-lbs.) tension.

8.0 Final Assembly

8.1 Final Electrical Measurements

MQXB17 was hipotted coil to ground, heaters to ground and heaters to coil at 5000 V. Coils were hipotted across midplanes at 3000V. Leakage in all cases is required to be less than 3 μA. All tests were successful. Hipot leakage values are shown in Table 8.1.1. In Table 8.1.1, coil to ground and quench protection heater (strip heater) to ground measurements were taken after the cold mass was completed. The quadrant-to-quadrant (midplane) measurements were taken slightly earlier, before the quadrant splices were made, because this hipot cannot be made after the quadrants are spliced together.

In Table 8.1.2, resistance in the individual quadrants was measured using voltage taps, while total resistance was measured through both voltage tabs and the magnet leads.

Hipot	Result
Coil to Ground	1026nA at 5000V
Strip heaters to Coil & Ground	765nA at 5000V
Coils Q1 to Coils Q2 across midplane	582nA at 3000V
Coils Q2 to Coils Q3 across midplane	160nA at 3000V
Coils Q3 to Coils Q4 across midplane	373nA at 3000V
Coils Q4 to Coils Q1 across midplane	384nA at 3000V

Table 8.1.1. Cold Mass Hipotting Data

Final electrical data is shown in Table 8.1.2.

	Resistance ohms		Ls mH	Q
Q1 – Quadrant total	0.5712		3.4498	4.8
Q2 – Quadrant total	0.5717		3.4584	4.8
Q3 – Quadrant total	0.5713		3.4705	4.9
Q4 – Quadrant total	0.5713		3.4223	4.9
	Resistance ohms		**Ls mH**	**Q**
Magnet Total	**V. Taps**	n/a	13.793	4.7
Magnet Total	**Leads**	2.294		

Table 8.1.2: Magnet Resistance, L and Q measurements.

Heater resistances are shown in Table 8.1.3:

Strip Heater	Resistance ohm
Circuit A	20.2747
Circuit B	20.1618

Table 8.1.3: Quench Protection (Strip) Heater resistance measurements

8.2 Mechanical Measurements

Design and actual finished longitudinal dimensions of the MQXB17 cold mass are shown in Figures 8.2.1 and 8.2.2. Figure 8.2.2 shows the longitudinal position of the magnetic center, from the measurements described at the end of Section 5.3.

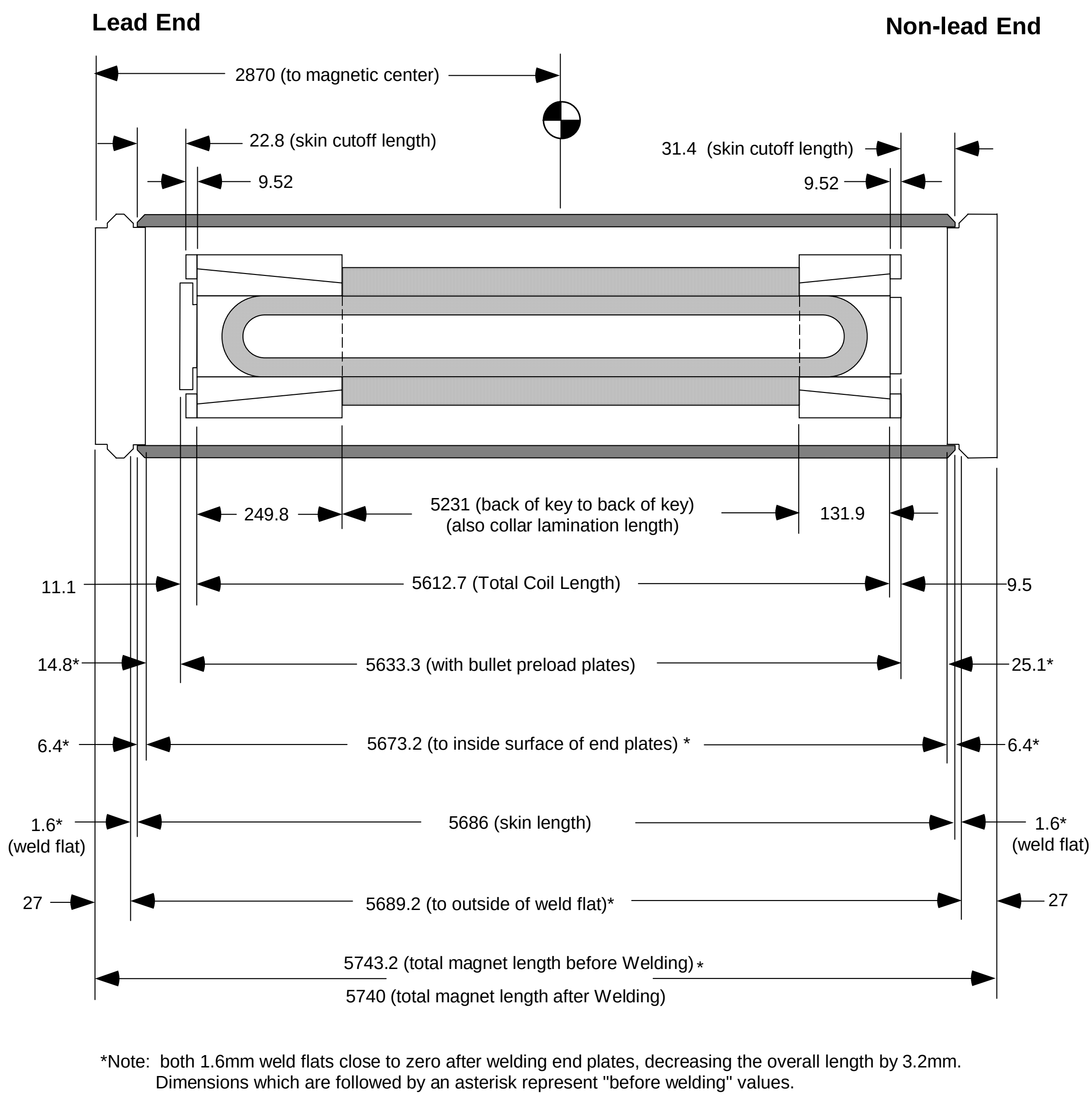

Figure 8.2.1: Design Dimensions of MQXB17

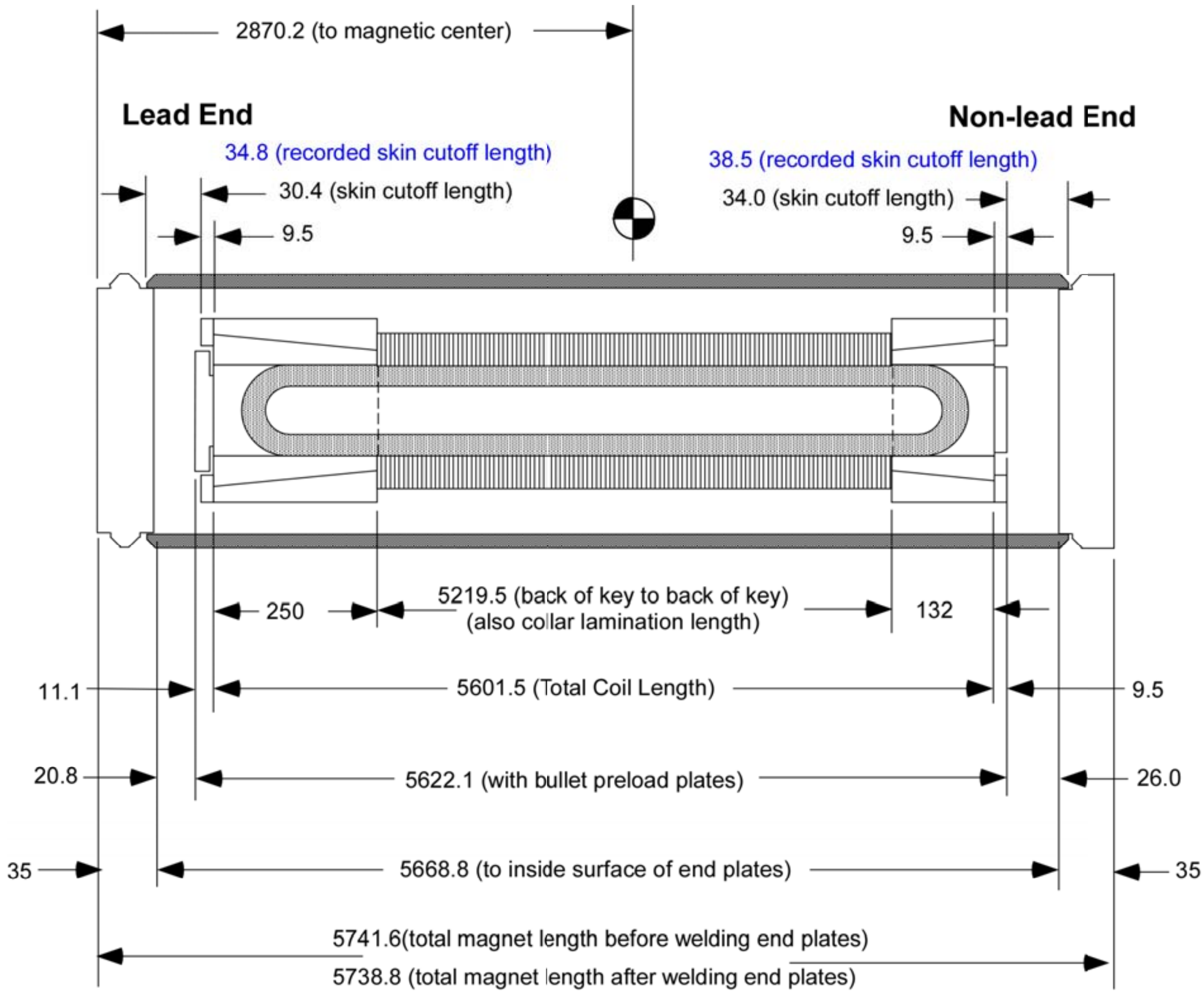

Figure 8.2.2: As-built Measured Dimensions of MQXB17

9.0 Discrepancies and Comments

Whenever an anomalous situation occurs during the construction of a magnet, a discrepancy report is filed. All discrepancy reports filed during the construction of the MQXB17 cold mass are listed in Table 9.0.1. Complete reports, with their dispositions and corrective actions, can be obtained from the FNAL Technical Division Process Engineering Department.

DRNo	Component SN	Discrepancy Description
HGQ-0517	MQXB17	While grooving G-11 Collet for heater wire routing, a nick was incurred in quadrant one outer coil. A total of three strands were damaged.
HGQ-0513	MQXBC-017	Heaters to coil and ground hipot failed @2194V. The coils to heater and ground hipot subsequently passed its hipot with a leakage of 1600 nA.
HGQ-0518	MQXB17	The large offset ¼”- thick washers used to bolt the lead end and non-lead end plates were not offset enough to allow the bolts to line up with the holes in the axial preload ring.
4116	MQXBC-017-0	Tapered ring diameter measurements taken in fully clamped state showed a lower than desired diameter increase when compared to the measurements taken before installation.
2524	MQXBo-087-0	One wedge was badly scratched and gouged on the edges.
4056	MQXBo-088-0	Coil failed initial LE-Compression test. The insulation of turn 15 and the insulation on the mating tooling was found to be damaged. The insulation was repaired and coil passed End Compression tests.

Table 9.0.1 MQXB17 Discrepancy Reports